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Inoue

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(54) **VEHICULAR ACTIVE SOUND EFFECT GENERATING APPARATUS**

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H03G 3/00 (2006.01)
G10K 15/02 (2006.01)
H04R 3/12 (2006.01)

(52) **U.S. Cl.**
CPC ***H03G 3/00*** (2013.01); ***G10K 15/02*** (2013.01); *H04R 3/12* (2013.01); *H04R 2499/13* (2013.01)

(58) **Field of Classification Search**
USPC 381/86, 302, 61, 111, 116, 120, 307, 59
See application file for complete search history.

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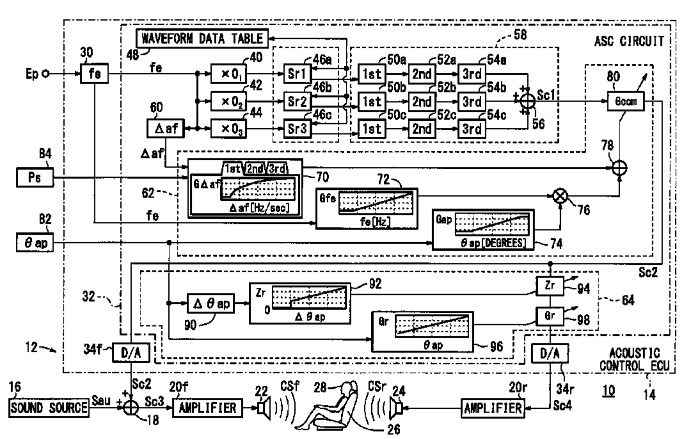
(57) **ABSTRACT**

A sound effect generating apparatus includes a delay unit for giving a delay to a sound effect output from a rear speaker depending on either an accelerator opening change which represents a change per unit time in an accelerator opening or the accelerator opening itself.

6 Claims, 4 Drawing Sheets



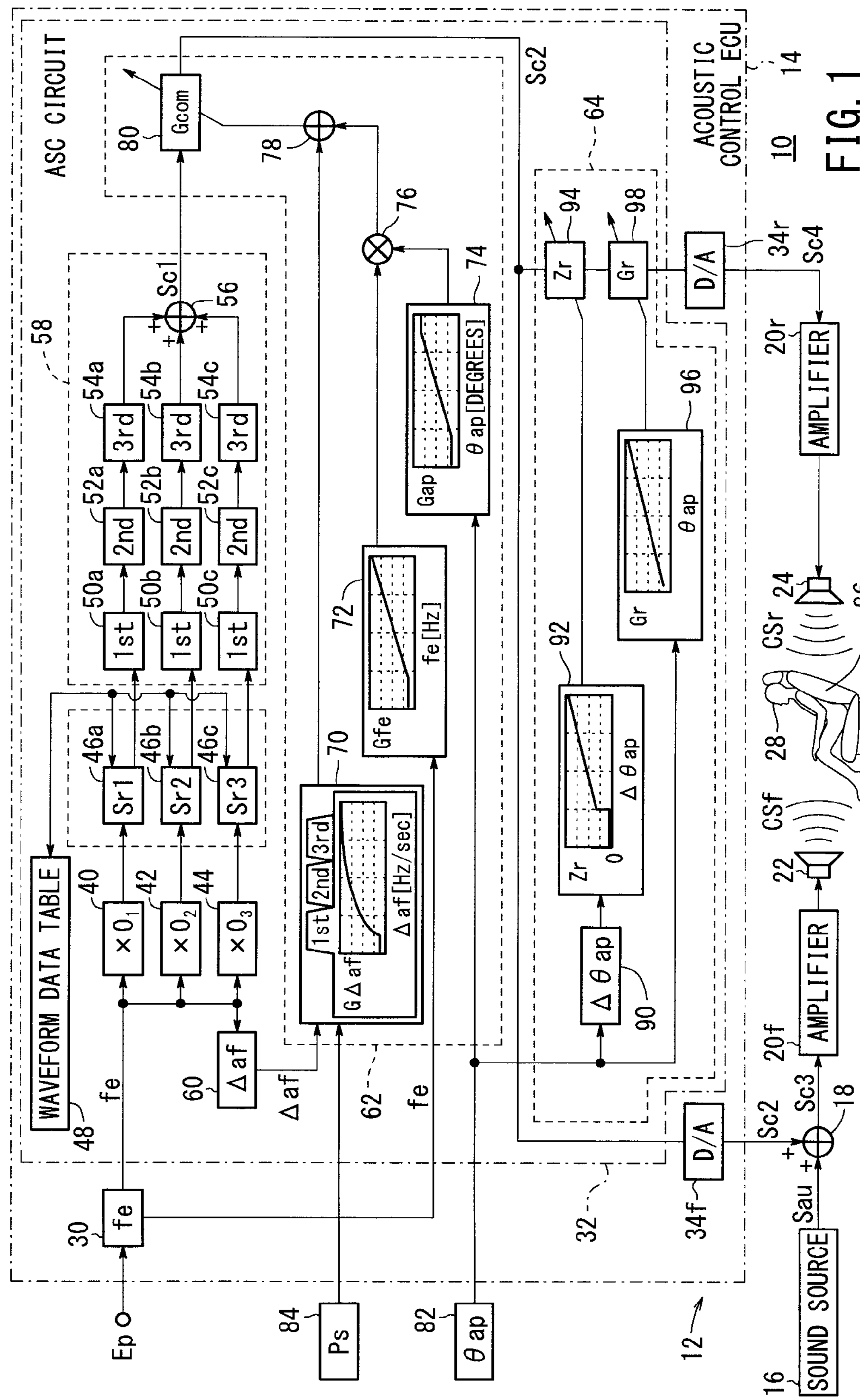

ASC CIRCUIT
ACOUSTIC CONTROL ECU
WAVEFORM DATA TABLE
Gcom
Sr1
Sr2
Sr3
1st
2nd
3rd
Sc1
Sc2
Sc3
Sc4
Δaf
Δaf[Hz/sec]
GΔaf
Gfe
fe[Hz]
Gap
θap[DEGREES]
Zr
Gr
Δθap
θap
D/A
AMPLIFIER
SOUND SOURCE
Sau
CSf
CSr
fe
Ep
Ps
10
12
14
16
18
20f
20r
22
24
26
28
30
32
34f
34r
40
42
44
46a
46b
46c
48
50a
50b
50c
52a
52b
52c
54a
54b
54c
56
58
60
62
64
70
72
74
76
78
80
82
84
90
92
94
96
98

FIG. 1

FIG. 2

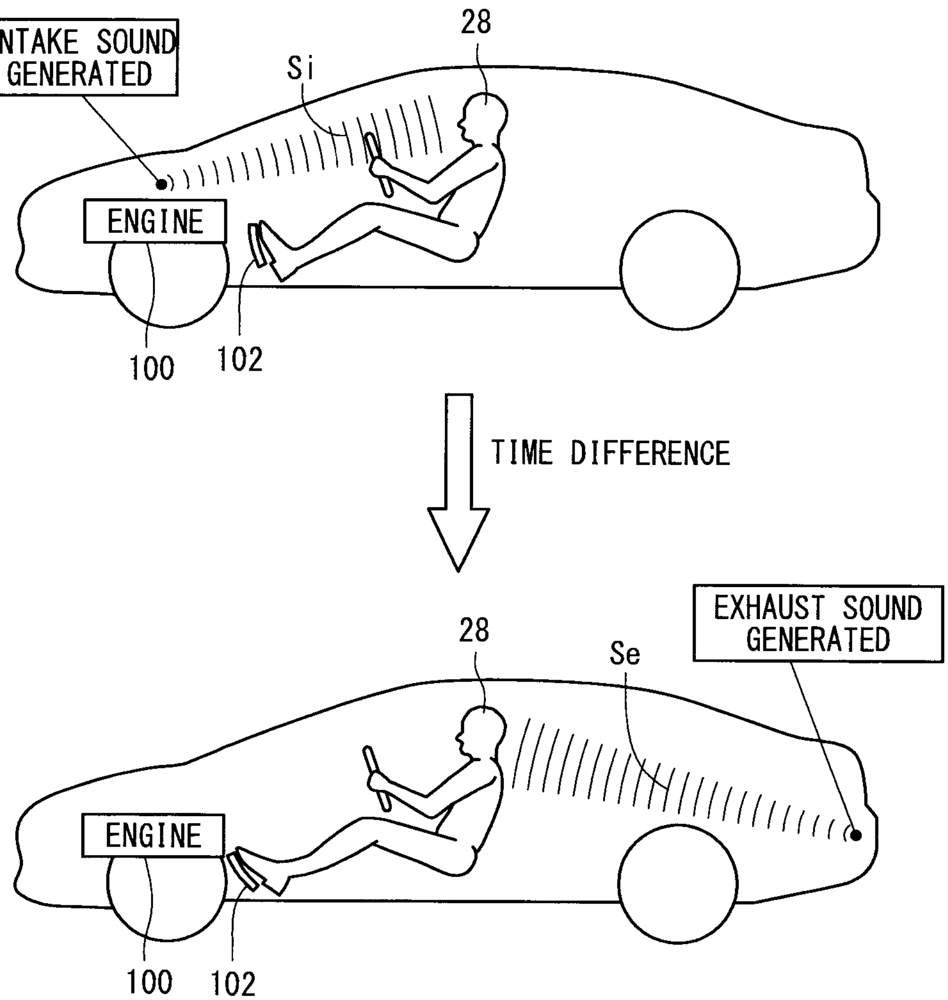

INTAKE SOUND GENERATED
28
Si
ENGINE
100
102
TIME DIFFERENCE
28
Se
EXHAUST SOUND GENERATED
ENGINE
100
102

FIG. 3

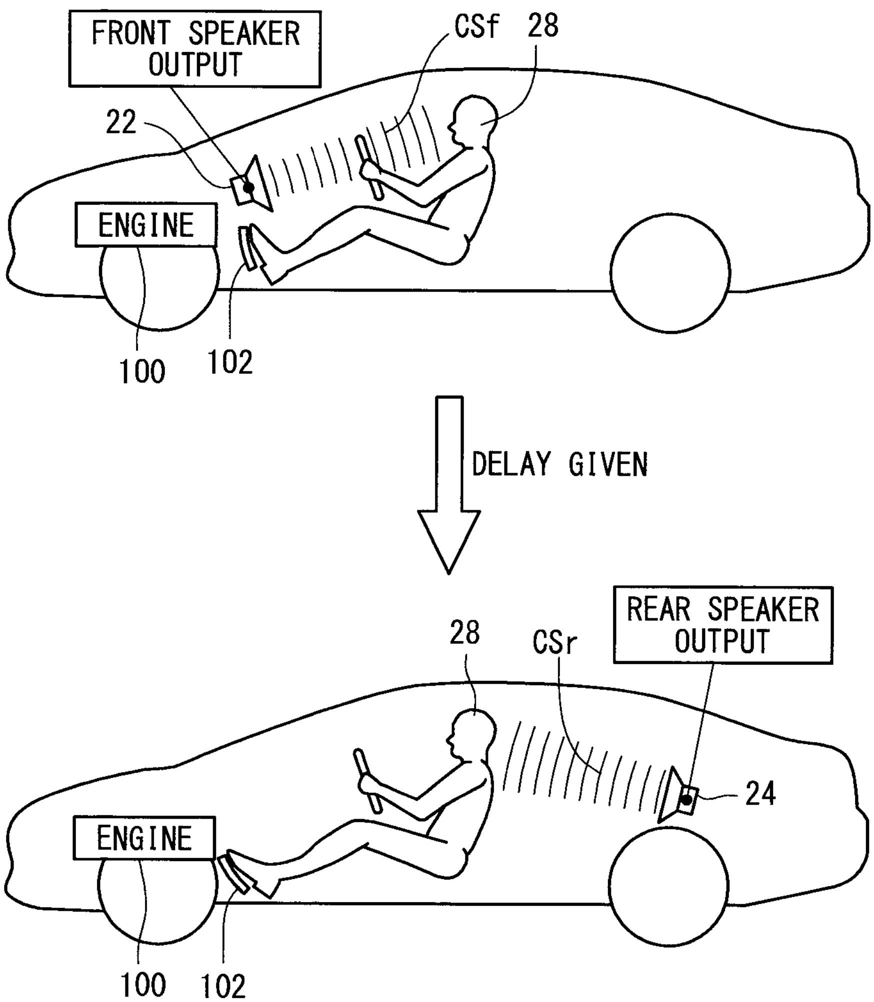
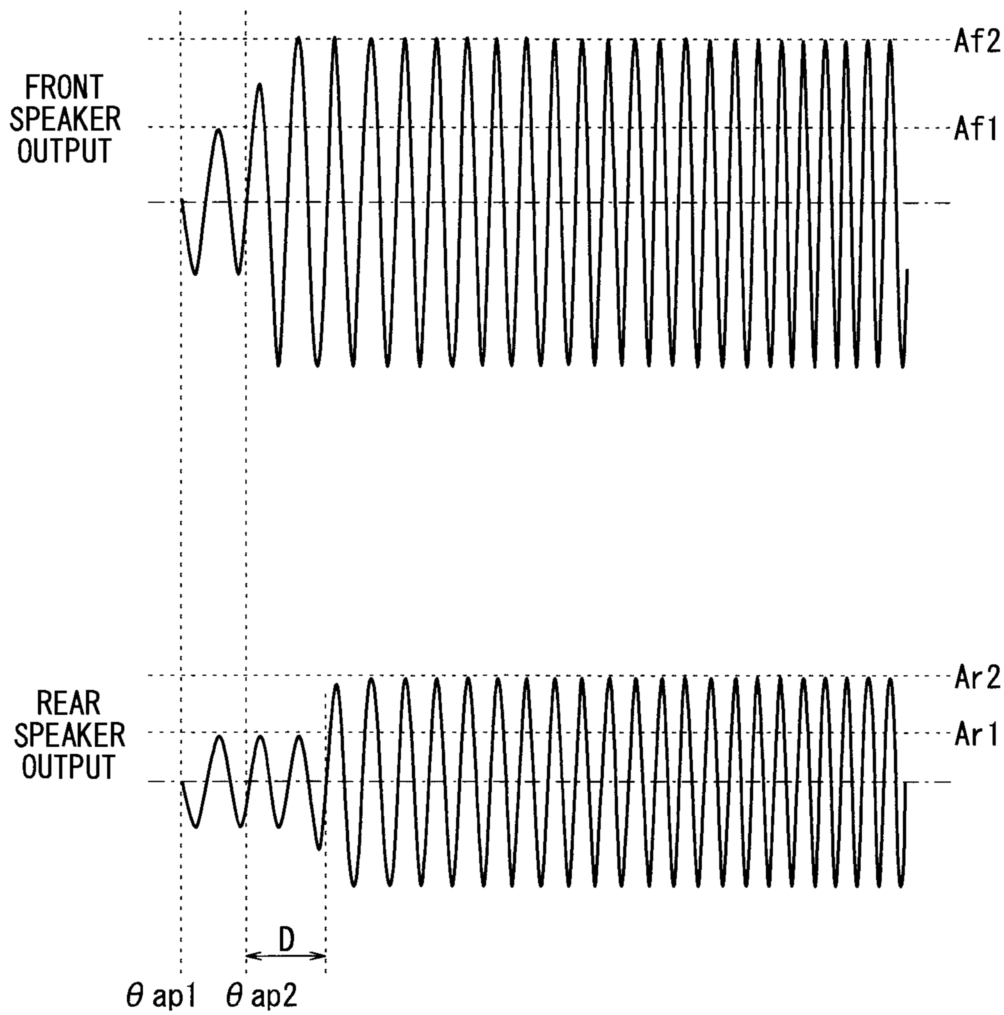

FRONT SPEAKER OUTPUT
CSf
28
22
ENGINE
100
102
DELAY GIVEN
28
CSr
REAR SPEAKER OUTPUT
24
ENGINE
100
102

FIG. 4


FRONT SPEAKER OUTPUT
Af2
Af1
REAR SPEAKER OUTPUT
Ar2
Ar1
D
θap1
θap2

VEHICULAR ACTIVE SOUND EFFECT GENERATING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2012-032555 filed on Feb. 17, 2012, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a vehicular active sound effect generating apparatus for generating a sound effect such as a pseudo-engine sound of a vehicle or the like.

2. Description of the Related Art

Sound effect generating apparatus also referred to as "ASC apparatus (Active Sound Control apparatus)") have been known in the art as apparatus for enhancing the acoustic effect in the passenger compartments of vehicles. See, for example, U.S. Patent Application Publication No. 2008/0310642 (hereinafter referred to as "US2008/0310642A1") and U.S. Patent Application Publication No. 2009/0028353 (hereinafter referred to as "US2009/0028353A1".

US2008/0310642A1 discloses that a delay Zc**2** produced by a rear speaker **22***b* is made longer than a delay Zc**1** produced by a front speaker **22***a* (FIGS. 5 through 6D, paragraphs [0085] through [0102]). The lengths of the delays Zc**1**, Zc**2** may be of not only fixed values, but may be varied depending on an increase or reduction in an engine rotational frequency change Δaf [Hz/second] or a vehicle speed change [km/hour/second] (paragraphs [0141] through [0144]).

US2009/0028353A1 is aimed at providing an active sound effect generating apparatus which is capable of generating natural sound effects ([0008]). In order to achieve the object, the active sound effect generating apparatus **101** disclosed in US2009/0028353A1 has a control means **201** (fourth acoustic adjustor **54** and fifth acoustic adjustor **55**) which adjusts the amplitudes of reference signals Sr**1**, Sr**2**, Sr**3** (intermediate signals Si**4**, Si**5**) depending on an engine rotational frequency change Δaf [Hz/second] calculated by an engine rotational frequency change calculator **68** and an accelerator opening Aor [%] detected by an accelerator opening sensor **60**, for thereby determining the amplitude of a control signal Sc (Abstract).

SUMMARY OF THE INVENTION

According to US2008/0310642A1, as described above, the length of the delay Zc**2** produced by the rear speaker **22***b* may be varied depending on an increase or reduction in the engine rotational frequency change Δaf or the vehicle speed change (paragraphs [0141] through [0144]). However, the engine rotational frequency change Δaf and the vehicle speed change represent vehicle states, and may not necessarily reflect the operation by the driver of the accelerator pedal. For example, when the vehicle runs uphill, even if the driver depresses the accelerator pedal deeply, the engine rotational frequency does not go higher than when the vehicle runs on a flat road. However, US2008/0310642A1 does not deal with such a situation.

US2009/0028353A1 discloses the adjustment of the amplitudes of the reference signals Sr**1**, Sr**2**, Sr**3** (intermediate signals Si**4**, Si**5**) depending on the accelerator opening Aor (Abstract). Such a process is premised on an arrangement wherein a front speaker generates a sound effect (see FIGS. 1, 10, and 15). US2009/0028353A1 is silent about delaying a sound effect generated by a rear speaker.

It is an object of the present invention to provide a sound effect generating apparatus which is capable of appropriately generating a sound effect from a rear speaker.

According to the present invention, there is provided a vehicular active sound effect generating apparatus comprising a waveform data table for storing waveform data of one period, a rotational frequency detecting unit for detecting a rotational frequency of an engine of a vehicle, a reference signal generating unit for generating a harmonic reference signal based on the rotational frequency by reading the waveform data from the waveform data table, a control signal generating unit for generating a control signal to generate a sound effect to be output into a passenger compartment of the vehicle, based on the reference signal, an accelerator opening detecting unit for detecting an accelerator opening of the vehicle, an amplitude-adjusted control signal generating unit for generating an amplitude-adjusted control signal by adjusting an amplitude of the control signal depending on the accelerator opening, a plurality of speakers for outputting the sound effect based on the amplitude-adjusted control signal, wherein the speakers include a front speaker positioned in a front portion of the vehicle and a rear speaker positioned in a rear portion of the vehicle, and a delay unit for giving a delay to a sound effect output from the rear speaker depending on either an accelerator opening change which represents a change per unit time in the accelerator opening or the accelerator opening itself.

According to the present invention, a delay depending on the accelerator opening change or the accelerator opening is given to the sound effect output from the rear speaker. Therefore, it is possible to produce a sound effect that reflects how the accelerator pedal of the vehicle is operated by the driver of the vehicle. For example, if the accelerator opening changes sharply, then the sound effect from the rear speaker is output with a delay with respect to a sound effect from the front speaker, thus outputting a sound effect taking into account the time difference between an intake sound and an exhaust sound and also enhancing a sound source movement feel (acceleration feel) which the driver has.

The delay unit may give a delay having a predetermined amount to the sound effect output from the rear speaker when the accelerator opening change exceeds a threshold value. Thus, a delay can be generated only when the driver depresses the accelerator pedal, for example.

The delay unit may change an amount of the delay given to the sound effect output from the rear speaker, depending on a magnitude of the accelerator opening change. Consequently, it is possible to reflect how the accelerator pedal is operated by the driver on the delay for achieving an enhanced sound effect.

An amplitude of the sound effect output from the rear speaker may be set to a value smaller than an amplitude of a sound effect output from the front speaker. Usually, sounds related to the actual operation of the engine (intake sound, exhaust sound, etc.) are stronger from a front portion of the vehicle than from a rear portion of the vehicle. Therefore, the above amplitude setting makes it possible to produce a natural sound effect.

The amplitude-adjusted control signal generating unit may adjust the amplitude of the control signal depending on the rotational frequency and the accelerator opening. It is thus possible to output a sound effect which reflects both the operating state of the engine and the operated state of the accelerator pedal.

The vehicular active sound effect generating apparatus may further comprise a rotational frequency change calculating unit for calculating a rotational frequency change which represents a change per unit time in the rotational frequency. The amplitude-adjusted control signal generating unit may adjust the amplitude of the control signal depending on the rotational frequency change and the accelerator opening. Therefore, it is possible to output a sound effect which reflects both the operated state of the engine and the operating state of the accelerator pedal.

The above and other objects, features, and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which a preferred embodiment of the present invention is shown by way of illustrative example.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a vehicle incorporating an acoustic control electronic control unit (hereinafter referred to as "acoustic control ECU") having the function of a sound effect generating apparatus according to an embodiment of the present invention;

FIG. **2** is a view illustrating the timings of generating an intake sound and an exhaust sound of an engine when an accelerator pedal is depressed;

FIG. **3** is a view illustrating a delay produced between a sound effect (front control sound) generated by front speakers and a sound effect (rear control sound) generated by rear speakers; and

FIG. **4** is a diagram illustrating the difference between an output sound from the front speakers and an output sound from the rear speakers.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[A. Embodiment]

1. Overall and Local Arrangements:

(1-1. Overall Arrangement)

FIG. **1** shows in block form a vehicle **10** incorporating an acoustic control electronic control unit **14** (hereinafter referred to as "acoustic control ECU **14**" or "ECU **14**") having the function of a sound effect generating apparatus (ASC apparatus) according to an embodiment of the present invention. The vehicle **10** comprises a gasoline-powered vehicle, but may comprise an electric vehicle, a fuel battery vehicle, or the like.

The vehicle **10** includes an acoustic system **12** having, in addition to the acoustic control ECU **14**, a sound source **16**, an adder **18**, a pair of amplifiers **20***f*, **20***r*, a plurality of front speakers **22**, and a plurality of rear speakers **24**.

The acoustic control ECU **14** may have, in addition to the function of the ASC apparatus, the function of an active noise control apparatus (hereinafter referred to as "ANC apparatus"). The ANC apparatus may be of a configuration disclosed in U.S. Patent Application Publication No. 2004/0247137 and U.S. Pat. No. 7,062,049, for example.

When the ECU **14** functions as the ASC apparatus, it outputs a control signal Sc**2** (amplitude adjustment control signal) representing a sound effect that is synchronous with a muffled engine sound (pseudo-engine sound).

The sound source **16**, which comprises an audio device and/or navigation device, outputs an audio signal Sau representing music and/or route guidance voice to the adder **18**.

The adder **18** combines the control signal Sc**2** from the ECU **14** and the audio signal Sau from the sound source **16** into a control signal Sc**3**, which is applied through the amplifier **20***f* to the front speakers **22**. The amplifier **20***r* amplifies a control signal Sc**4** from the ECU **14** and outputs the amplified control signal Sc**4** to the rear speakers **24**.

The front speakers **22** are installed near a front seat **26** (e.g., driver's seat) of the vehicle **10**, for example, in front door panels on both sides, kick panels on both sides (e.g., panels on a side of a driver's leg space and a side of another leg space), or in a roof above the driver's seat **26**. The front speakers **22** output a front control sound CSf represented by the control signal Sc**3** from the adder **18** toward a driver **28** seated on the front seat **26**. When the ECU **14** functions as the ANC device, the front speakers **22** output the front control sound CSf as a canceling sound for canceling the muffled engine sound. When the ECU **14** functions as the ASC device, the front speakers **22** output the front control sound CSf as a sound effect representing a pseudo-engine sound.

The rear speakers **24** are installed near rear seats, not shown, of the vehicle **10**, e.g., in rear door panels on both sides or a roof above the rear seats. The rear speakers **24** output a rear control sound CSr represented by the control signal Sc**4** from the ECU **14** toward the driver **28**. When the ECU **14** functions as the ANC device, the rear speakers **24** output the rear control sound CSr as a canceling sound for canceling the muffled engine sound. When the ECU **14** functions as the ASC device, the rear speakers **24** output the rear control sound CSr as a sound effect representing a pseudo-engine sound.

(1-2. Acoustic Control ECU **14**)

(1-2-1. Overall Arrangement)

As shown in FIG. **1**, the ECU **14** (vehicular active sound effect generating apparatus) has an engine rotational frequency detector **30** (hereinafter also referred to as "fe detector **30**"), an ASC circuit **32**, and digital/analog converters **34***f*, **34***r* (hereinafter also referred to as "D/A converters **34***f*, **34***r*").

The fe detector **30** (rotational frequency detecting unit) detects an engine rotational frequency fe [Hz] based on engine pulses Ep from a fuel injection controller {hereinafter referred to as "FI ECU" (Fuel Injection Electronic Control Unit)}, not shown, that controls fuel injection in an engine **100** (see FIG. **2**). The fe detector **30** outputs the detected engine rotational frequency fe to the ASC circuit **32**.

The ASC circuit **32** generates a sound effect representing a pseudo-engine sound to enhance an acoustic effect in the passenger compartment of the vehicle **10**, e.g., to intensify a speed change of the vehicle **10**.

As shown in FIG. **1**, the ASC circuit **32** generates an output signal, i.e., the control signal Sc**2**, for the front speakers **22** and an output signal, i.e., the control signal Sc**4**, for the rear speakers **24**. The control signal Sc**2** is converted into an analog control signal Sc**2** by the D/A converter **34***f*. The analog control signal Sc**2** is output to the adder **18**. The control signal Sc**4** is converted into an analog control signal Sc**4** by the D/A converter **34***r*. The analog control signal Sc**4** is output to the amplifier **20***r*.

(1-2-2. Details of ASC Circuit **32**)

(1-2-2-1. Overall Arrangement of ASC Circuit **32**)

As shown in FIG. **1**, the ASC circuit **32** includes multipliers **40**, **42**, **44**, reference signal generators **46***a*, **46***b*, **46***c*, a waveform data table **48**, a control signal generator **58** (control signal generating unit) having first acoustic correctors **50***a*, **50***b*, **50***c*, second acoustic correctors **52***a*, **52***b*, **52***c*, and third acoustic correctors **54***a*, **54***b*, **54***c*, a frequency change detector **60** (hereinafter also referred to as "Δaf detector **60**"), an entire sound volume corrector **62**, and a rear sound volume corrector **64**. The above components of the ASC circuit **32**, except for the entire sound volume corrector **62** and the rear sound volume corrector **64**, may be those disclosed in U.S. Patent Application Publication No. 2006/0215846 (hereinafter referred to as "US2006/0215846A1") and/or US2009/0028353A1 (see FIG. 12 of US2006/0215846A1 and/or FIG. 1 of US2009/0028353A1).

The multipliers **40**, **42**, **44** generate harmonic signals having frequencies which are represented by predetermined degrees (multiples) of the engine rotational frequency fe. Specifically, the multiplier **40** generates an O_1-degree, e.g., second, harmonic signal, the multiplier **42** an O_2-degree, e.g., third, harmonic signal, and the multiplier **44** an O_3-degree, e.g., fourth, harmonic signal.

The reference signal generators **46**a, **46**b, **46**c (reference signal generating unit) generate reference signals Sr**1**, Sr**2**, Sr**3**, respectively, based on the harmonic signals from the multipliers **40**, **42**, **44** and waveform data stored in the waveform data table **48**, and output the generated reference signals Sr**1**, Sr**2**, Sr**3** to the first acoustic correctors **50**a, **50**b, **50**c, respectively.

The first acoustic correctors **50**a, **50**b, **50**c perform, on the reference signals Sr**1**, Sr**2**, Sr**3**, a planarizing process for generating a control sound CS as a sound effect that is felt as linear with respect to the driver's action to accelerate the vehicle **10**, at the ears of the driver **28** (see paragraphs [0069] through [0076] of US2006/0215846A1). The second acoustic correctors **52**a, **52**b, **52**c perform, on the reference signals Sr**1**, Sr**2**, Sr**3**, a frequency intensifying process for intensifying only a desired frequency of the control sound CS as the sound effect (see paragraphs [0079] through [0082] of US2006/0215846A1). The third acoustic correctors **54**a, **54**b, **54**c perform a degree-dependent correcting process for correcting the reference signals Sr**1**, Sr**1**, Sr**3** depending on the degrees (see paragraph [0088] of US2006/0215846A1).

The reference signals Sr**1**, Sr**2**, Sr**3** that have been processed by the first acoustic correctors **50**a, **50**b, **50**c, the second acoustic correctors **52**a, **52**b, **52**c, and the third acoustic correctors **54**a, **54**b, **54**c are combined into a control signal Sc**1** by an adder **56**.

The Δaf detector **60** (rotational frequency change calculating unit) detects a change per unit time in the engine rotational frequency fe (hereinafter referred to as "frequency change Δaf") [Hz/s] based on the engine rotational frequency fe from the fe detector **30**, and outputs the detected frequency change Δaf to the entire sound volume corrector **62**.

The entire sound volume corrector **62** (amplitude-adjusted control signal generating unit) corrects the sound volumes of the front control sound CSf and the rear control sound CSr (sound effects) depending on the operating state of the engine **100** (see FIG. **2**), the operated state of an accelerator pedal **102**, and the shifted position of a gearshift lever, not shown (hereinafter referred to as "shifted position Ps"). The rear sound volume corrector **64** corrects the sound volumes and output timing of the rear speakers **24** depending on the depressed state of the accelerator pedal **102**.

(1-2-2-2. Details of Entire Sound Volume Corrector **62**)

As described above, the entire sound volume corrector **62** corrects the front control sound CSf (sound effect) output by the front speakers **22** and the rear control sound CSr (sound effect) output by the rear speakers **24** depending on the operating state of the engine **100**, the operated state of the accelerator pedal **102**, and the shifted position Ps. The operating state of the engine **100** is represented by the engine rotational frequency fe and the frequency change Δaf. The operated state of the accelerator pedal **102** is represented by the angle [°] through which the accelerator pedal **102** is depressed (hereinafter referred to as "accelerator opening θap"), detected by an accelerator opening sensor **82** (see FIG. **1**) as an accelerator opening detecting unit. The shifted position Ps is detected by a gearshift position sensor **84**.

The entire sound volume corrector **62** has a first gain setter **70**, a second gain setter **72**, a third gain setter **74**, a multiplier **76**, an adder **78**, and an entire sound volume correction filter **80**.

The first gain setter **70** sets a gain (hereinafter referred to as "frequency change gain GΔaf" or "first gain GΔaf") based on a shift position Ps and a frequency change Δaf. Specifically, maps representing the relationship between frequency changes Δaf and first gains GΔaf are established in advance for respective different shift positions Ps (first, second, and third gear positions, etc.). One of the maps is selected based on a shift position Ps indicated by the shift position sensor **84**. Using the selected map, the first gain setter **70** sets a first gain GΔaf based on the frequency change Δaf detected by the Δaf detector **60**.

The second gain setter **72** sets a gain ((hereinafter referred to as "frequency gain Gfe" or "second gain Gfe") based on an engine rotational frequency fe. Specifically, a map representing the relationship between engine rotational frequencies fe and second gains Gfe is established in advance. Using the map, the second gain setter **72** sets a second gain Gfe based on the engine rotational frequency fe detected by the fe detector **30**.

The third gain setter **74** sets a gain (hereinafter referred to as "accelerator opening gain Gap" or "third gain Gap") based on an accelerator opening θap. Specifically, a map representing the relationship between accelerator openings θap and third gains Gap is established in advance. Using the map, the third gain setter **74** sets a third gain Gap based on the accelerator opening θap detected by the accelerator opening sensor **82**.

As described above, the third gain Gap is a gain that is set based on the accelerator opening θap. Therefore, even if there is a deviation between the accelerator opening θap and the engine rotational frequency fe when the vehicle **10** travels uphill or downhill, it is possible to generate sound effects (front control sound CSf and rear control sound CSr) taking into account how the accelerator pedal **102** is operated by the driver **28**.

For example, when the vehicle **10** runs uphill, the engine rotational frequency fe increases little even if the driver **28** depresses the accelerator pedal **102** deeply. However, a large sound effect can be produced depending on the accelerator opening θap for an enhanced acoustic effect in the passenger compartment. Conversely, when the vehicle **10** runs downhill, the engine rotational frequency fe increases greatly even if the driver **28** depresses the accelerator pedal **102** little. However, since a small sound effect is produced depending on the accelerator opening θap, it is possible to keep the passenger compartment quiet.

A deviation between the accelerator opening θap and the engine rotational frequency fe may possibly occur if the vehicle **10** incorporates a system wherein the engine **100** is not directly connected to the accelerator pedal **102** and hence is not mechanically controlled by the accelerator pedal **102**, but is electrically controlled based on a signal related to the accelerator pedal **102** (so-called "steer-by-wire technology"), or a transmission that utilizes an optimum engine rotational frequency fe depending on the running state of the vehicle **10**, such as a continuously variable transmission (CVT). In case the vehicle **10** incorporates such a steer-by-wire technology or transmission, it is also possible to generate sound effects (front control sound CSf and rear control sound CSr) taking into account how the accelerator pedal **102** is depressed by the driver **28**, by using the third gain Gap.

The multiplier **76** multiplies the second gain Gfe (rotational frequency gain Gfe) set by the second gain setter **72** by the third gain Gap (accelerator opening gain Gap) set by the third gain setter **74**, and outputs the product to the adder **78**.

The adder **78** (fourth gain setter) adds the first gain GΔaf (frequency change gain GΔaf) set by the first gain setter **70** to the product determined by the multiplier **76** of the second gain Gfe set by the second gain setter **72** and the third gain Gap set by the third gain setter **74**, thereby calculating a sum gain (hereinafter referred to as "common corrective gain Gcom" or "fourth gain Gcom").

The entire sound volume correction filter **80** multiplies the control signal Sc**1** from the adder **56** by the fourth gain Gcom calculated by the adder **78**, generating a control signal Sc**2** (amplitude adjustment control signal). The entire sound volume correction filter **80** outputs the generated control signal Sc**2** to the D/A converter **34*f*** and the rear sound volume corrector **64**.

As described above, the entire sound volume corrector **62** corrects the control signal Sc**1** to generate the control signal Sc**2**, using the engine rotational frequency fe and the frequency change Δaf, which represent the operating state of the engine **100**, the accelerator opening θap representing the operated state of the accelerator pedal **102**, and the shift position Ps.

(1-2-2-3. Details of Rear Sound Volume Corrector **64**)

As described above, the rear sound volume corrector **64** corrects the sound volume and output timing of the rear speakers **24** depending on the operated state of the accelerator pedal **102**. The operated state of the accelerator pedal **102** is represented by the accelerator opening θap detected by the accelerator opening sensor **82**.

The rear sound volume corrector **64** has an accelerator opening change detector **90** (hereinafter also referred to as "Δθap detector **90**"), a delay setter **92**, a delay filter **94**, a fifth gain setter **96**, and a rear sound volume correction filter **98** (hereinafter also referred to as "filter **98**").

The Δθap detector **90** detects a change per unit time in the accelerator opening θap (hereinafter also referred to as "accelerator opening change Δθap") [°/s] based on the accelerator opening θap detected by the accelerator opening sensor **82**, and outputs the detected accelerator opening change Δθap to the delay setter **92**.

The delay setter **92** sets a delay (hereinafter referred to as "rear speaker delay Zr" or "delay Zr") based on the accelerator opening change Δθap. Specifically, a map representing the relationship between accelerator opening changes Δθap and delays Zr is established in advance. Using the map, the delay setter **92** sets a delay Zr based on the accelerator opening change Δθap detected by the Δθap detector **90**.

According to the present embodiment, when the accelerator opening change Δθap exceeds a predetermined threshold value (hereinafter referred to as "threshold value TH_Δθap"), the delay setter **92** generates a delay D. If the threshold value TH_Δθap is a positive value, then the delay setter **92** can generate a delay D only when the driver **28** depresses the accelerator pedal **102**.

The delay filter **94** adds the delay Zr calculated by the delay setter **92** to the control signal Sc**2** from the entire sound volume correction filter **80**, and then outputs the control signal Sc**2** with the delay Dr to the rear sound volume correction filter **98**.

As described above, the delay Zr is a delay that is set based on the accelerator opening change Δθap. Therefore, when the driver **28** depresses the accelerator pedal **102** greatly, then the sound effect produced by the rear speakers **24** is delayed from the sound effect produced by the front speakers **22**, thereby enhancing an acceleration feel which the driver **28** has.

The fifth gain setter **96** sets a gain (hereinafter referred to as "pedal operating gain Gr" or "fifth gain Gr") based on the accelerator opening θap. Specifically, a map representing the relationship between accelerator openings θap and fifth gains Gr is established in advance. Using the map, the fifth gain setter **96** sets a fifth gain Gr based on the accelerator opening θap detected by the accelerator opening sensor **82**.

The fifth gain Gr is used with respect to the sound effect produced by the rear speakers **24**. The sound effect produced by the rear speakers **24** is felt natural when it is not as strong as the sound effect produced by the front speakers **22**. According to the present embodiment, therefore, the fifth gain Gr is set such that sound effect produced by the rear speakers **24** is not as strong as the sound effect produced by the front speakers **22** (see FIG. **4**). More specifically, the fifth gain Gr is set to a value smaller than 1.

The fifth gain Gr is a gain that is set for the rear speakers **24** based on the accelerator opening θap. Consequently, it is possible to control the amplitude (hereinafter referred to as "amplitude Ar") of the sound effect produced by the rear speakers **24** depending on how the accelerator pedal **102** is operated by the driver **28**.

The rear sound volume correction filter **98** multiplies the control signal Sc**2** to which the delay Zr is added by the delay filter **94**, by the fifth gain Zr set by the fifth gain setter **96**, thereby generating a control signal Sc**4**. The rear sound volume correction filter **98** outputs the generated control signal Sc**4** to the D/A converter **34*r***.

As described above, the rear sound volume corrector **64** corrects the control signal Sc**2** to generate the control signal Sc**4**, using the accelerator opening θap (and the accelerator opening change Δθap based thereon) representing the pressed state of the accelerator pedal **102**.

2. Processing by Rear Sound Volume Corrector **64**:

A processing operation of the rear sound volume corrector **64** will be described in greater detail below.

FIG. **2** is a view illustrating the timings of generating an intake sound Si and an exhaust sound Se of the engine **100** when the accelerator pedal **102** is depressed. FIG. **3** is a view illustrating a delay D produced between the sound effect (front control sound CSf) generated by the front speakers **22** and the sound effect (rear control sound CSr) generated by the rear speakers **24** when the accelerator pedal **102** is depressed. FIG. **4** is a diagram illustrating the difference between an output sound from the front speakers **22** and an output sound from the rear speakers **24**.

(2-1. Time Difference Between Intake Sound Si and Exhaust Sound Se)

As shown in FIG. **2**, there is a time difference developed between the intake sound Si and the exhaust sound Se. Specifically, air that is introduced into the engine **100** through an intake manifold, etc., not shown, is subsequently discharged from the engine **100** through an exhaust manifold, etc. Therefore, if attention is focused on a flow of air from the intake manifold through the engine **100** to the exhaust manifold, a time difference is developed between the intake sound Si and the exhaust sound Se which are produced by the same air.

Therefore, when the amount of intake air and the amount of exhaust air are changed by the driver **28** depressing the accelerator pedal **102**, an increase in the exhaust sound Se appears with a delay from an increase in the intake sound Si.

(2-2. Delay D to Occur Between Front Control Sound CSf and Rear Control Sound CSr)

As described above, a time difference is developed between the intake sound Si and the exhaust sound Se. As shown in FIG. **3**, in view of the time difference, the ASC circuit **32** (rear sound volume corrector **64**) according to the present embodiment imparts a delay D to the sound effect from the rear speakers **24** (rear control sound CSr) with respect to the sound effect from the front speakers **22** (front control sound CSf).

For example, as shown in FIG. **4**, if the accelerator opening θap changes from θap**1** to θap**2**, then a delay D is generated depending on the change in the accelerator opening θap (accelerator opening change Δθap). Therefore, when the driver **28** depresses the accelerator pedal **102** greatly, for example, the sound effect from the rear speakers **24** is output with a delay from the sound effect from the front speakers **22**, thus enhancing an acceleration feel which the driver **28** has. The delay D may not necessarily be the same as the time difference between the actual intake sound Si and the actual exhaust sound Se, but may be different from the time difference, i.e., may be longer or shorter than the time difference, to produce a desired sound effect for an enhanced acceleration feel.

According to the present embodiment, as described above, when the accelerator opening change Δθap exceeds the threshold value TH_Δθap, a delay D is produced. If the threshold value TH_Δθap is set to a positive value, then a delay D is produced only when the driver **28** depresses the accelerator pedal **102** for accelerating the vehicle **10**.

(2-3. Setting of Fifth Gain Gr)

The sound effect produced by the rear speakers **24** is felt natural when it is not as strong as the sound effect produced by the front speakers **22**. Since the fifth gain Gr is used with respect to the sound effect produced by the rear speakers **24**, the fifth gain Gr according to the present embodiment is set such that sound effect produced by the rear speakers **24** is not as strong as the sound effect produced by the front speakers **22**.

For example, as shown in FIG. **4**, when the accelerator opening θap is θap**1**, the amplitude Ar**1** of the rear control sound CSr is smaller than the amplitude Af**1** of the front control sound CSf. When the accelerator opening θap is θap**2**, the amplitude Ar**2** of the rear control sound CSr is smaller than the amplitude Af**2** of the front control sound CSf.

3. Advantages of the Present Embodiment:

According to the present embodiment, as described above, a delay D depending on the accelerator opening change Δθap is added to the sound effect output from the rear speakers **24** (rear control sound CSr). Therefore, it is possible to produce a sound effect that reflects how the accelerator pedal **102** is operated by the driver **28**. For example, if the accelerator opening θap changes sharply, then the sound effect from the rear speakers **24** (rear control sound CSr) is output with a delay with respect to the sound effect from the front speakers **22** (front control sound CSf), thus outputting a sound effect taking into account the time difference between the intake sound Si and the exhaust sound Se and also enhancing a sound source movement feel (acceleration feel) which the driver **28** has.

According to the present embodiment, the rear sound volume corrector **64** of the ASC circuit **32** gives a delay D to the sound effect produced by the rear speakers **24** when the accelerator opening change Δθap exceeds the threshold value TH_Δθap. Consequently, a delay D is produced only when the driver **28** depresses the accelerator pedal **102**.

According to the present embodiment, the rear sound volume corrector **64** of the ASC circuit **32** changes the amount of a delay D given to the sound effect produced by the rear speakers **24** (rear control sound CSr), depending on the magnitude of the accelerator opening change Δθap. It is thus possible to reflect the operated state of the accelerator pedal **102** more in the delay D for thereby producing an enhanced sound effect.

According to the present embodiment, the amplitude Ar of the sound effect from the rear speakers **24** is set to a value smaller than the amplitude Af of the sound effect from the front speakers **22** (see FIG. **4**). Usually, sounds related to the actual operation of the engine **100** (intake sound Si, exhaust sound Se, etc.) are stronger from a front portion of the vehicle **10** than from a rear portion of the vehicle **10**. Therefore, the above amplitude setting makes it possible to produce a more natural sound effect.

According to the present embodiment, the entire sound volume corrector **62** of the ASC circuit **32** adjusts the amplitude of the control signal Sc**1** depending on the engine rotational frequency change Δaf, the engine rotational frequency fe, and the accelerator opening θap (see FIG. **1**). It is thus possible to output a sound effect (front control sound CSf and rear control sound CSr) which reflects both the operating state of the engine **100** and the operated state of the accelerator pedal **102**.

According to the present embodiment, the magnitude of the sound effects (acceleration sound, etc.) output from the front speakers **22** and the rear speakers **24** is determined based on the first gain GΔaf for the engine rotational frequency change Δaf which represents the operating state of the engine **100** and the third gain Gap for the accelerator opening θap which represents how the driver **28** operates the accelerator pedal **102**. The third gain Gap based on the accelerator opening θap is weighed depending on the engine rotational frequency fe by being multiplied by the second gain Gfe based on the engine rotational frequency fe. Therefore, the two gains GΔaf, Gap which represent the operating state of the engine **100** and the operated state of the accelerator pedal **102** are generated parallel to each other, and the magnitude of a sound effect (acceleration sound, etc.) is determined by the sum of the gains GΔaf, Gap.

Consequently, the sound effect that is produced when the engine rotational frequency fe changes little even if the accelerator pedal **102** is depressed deeply, i.e., the accelerator opening θap is large, at the time the vehicle **10** is going uphill, is prevented from becoming unnecessarily small. The sound effect that is produced when the engine rotational frequency fe changes greatly even if the accelerator pedal **102** is not depressed deeply, i.e., the accelerator opening θap is small, at the time the vehicle **10** is going downhill, is prevented from becoming unnecessarily large. Therefore, a more natural sound effect (acceleration sound, etc.) can be produced.

[B. Applications of the Invention]

The present invention is not limited to the above embodiment, but may adopt various arrangements based on the disclosure of the present description. For example, the present invention may adopt the following arrangements:

1. Target Sounds:

In the above embodiment, the vehicle **10** comprises a gasoline-powered vehicle, and the control sounds CSf, CSr as the sound effects output from the front speakers **22** and the rear speakers **24** represent a pseudo-engine sound. However, the sound effect is not limited to the pseudo-engine sound, as long as it is a pseudo-operating sound of a drive source. If the vehicle **10** comprises an electric vehicle, then the control sounds CSf, CSr may represent a pseudo-propulsive-motor sound, and if the vehicle **10** comprises a fuel battery vehicle, then the control sounds CSf, CSr may represents a pseudo-compressor sound.

2. Entire Sound Volume Corrector **62**:

In the above embodiment, the fourth gain Gcom is set depending on a combination of the rotational frequency change Δaf, the engine rotational frequency fe, the accelerator opening θap, and the shift position Ps. However, the fourth gain Gcom may be set depending on one, two, or three of the rotational frequency change Δaf, the engine rotational frequency fe, the accelerator opening θap, and the shift position Ps.

Alternatively, in setting the fourth gain Gcom, a vehicle speed V [km/h] of the vehicle **10** may be used instead of the engine rotational frequency fe, or a vehicle speed change Δav [km/h/s] may be used instead of the rotational frequency change Δaf. In particular, if the vehicle speed V is used to adjust the gain of a reference signal or a control signal as disclosed in US2009/0028353A1 (see FIG. **1** thereof), then at least one of the vehicle speed V and the vehicle speed change Δav should preferably be used.

Alternatively, if the vehicle **10** comprises an electric vehicle, then the fourth gain Gcom may be set based on either one or both of the rotational frequency [Hz] of the traction motor of the vehicle **10** and the rotational frequency change [Hz/s] of the traction motor.

Further alternatively, if attention should be focused on the processing operation of the rear sound volume corrector **64** or the like, then the entire sound volume corrector **62** may be dispensed with.

3. Rear Sound Volume Corrector **64**:

(3-1. Delaying Process by Delay Filter **94**)

In the above embodiment, the rear sound volume corrector **64** has the delay filter **94** for adding the delay D and the rear sound volume correction filter **98** for adjusting the amplitude. If emphasis is to be placed on adding the delay D, then the amplitude adjustment by the rear sound volume correction filter **98** may be dispensed with. Conversely, if emphasis is to be placed on adjusting the amplitude by the rear sound volume correction filter **98**, then the addition of the delay D by the delay filter **94** may be dispensed with. If attention should be focused on the processing operation of the entire sound volume corrector **62**, then the rear sound volume corrector **64** may be dispensed with.

In the above embodiment, the amount of the delay D is changed based on the accelerator opening change Δθap (see the delay setter **92** shown in FIG. **1**). However, another approach may be possible insofar as the delay D is set depending on the accelerator opening change Δθap. For example, the amount of the delay D may be of a fixed value, and when the accelerator opening change Δθap exceeds a predetermined threshold value (hereinafter referred to as "threshold value TH_Δθap**2**"), the delay D (fixed value) may be generated, and when the accelerator opening change Δθap is smaller than the threshold value TH_Δθap**2**, the delay D may not be generated.

In the above embodiment, the delay D used in the delay filter **94** is set based on the accelerator opening change Δθap. However, the delay D may be set according to different processes insofar as it is based on the operated state of the accelerator pedal **102**. For example, the delay D may be changed based on the accelerator opening θap in addition to or instead of the accelerator opening change Δθap. This process makes it possible to keep the delay D at a maximum level when the accelerator pedal **102** is continuously depressed to its maximum stroke, thus producing a sound effect according to a new approach.

(3-2. Amplitude Adjustment by Rear Sound Volume Correction Filter **98**)

In the above embodiment, the rear sound volume correction filter **98** changes the fifth gain Gr (pedal operating gain Gr) depending on the accelerator opening θap. If this process is not important, the fifth gain Gr may be of a fixed value, or the amplitude adjustment by the rear sound volume correction filter **98** may be dispensed with.

The fifth gain Gr according to the above embodiment is set to 1 or smaller so that the sound effect produced by the rear speakers **24** is smaller than the sound effect produced by the front speakers **22**. However, the fifth gain Gr may be allowed to be 1 or greater.

What is claimed is:

1. A vehicular active sound effect generating apparatus comprising:

- a waveform data table for storing waveform data of one period;
- a rotational frequency detecting unit for detecting a rotational frequency of an engine of a vehicle;
- a reference signal generating unit for generating a harmonic reference signal based on the rotational frequency by reading the waveform data from the waveform data table;
- a control signal generating unit for generating a control signal to generate a sound effect to be output into a passenger compartment of the vehicle, based on the reference signal;
- an accelerator opening detecting unit for detecting an accelerator opening of the vehicle;
- an amplitude-adjusted control signal generating unit for generating an amplitude-adjusted control signal by adjusting an amplitude of the control signal depending on the accelerator opening;
- a plurality of speakers for outputting the sound effect based on the amplitude-adjusted control signal;
- wherein the speakers include a front speaker positioned in a front portion of the vehicle and a rear speaker positioned in a rear portion of the vehicle; and
- a delay unit for giving a delay to a sound effect output from the rear speaker, such that the sound effect output from the rear speaker is delayed in comparison with a sound effect output from the front speaker, depending on both an accelerator opening change which represents a change per unit time in the accelerator opening and the accelerator opening itself,
- wherein the delay unit changes an amount of the delay given to the sound effect output from the rear speaker, depending on a magnitude of the accelerator opening change and the accelerator opening itself so as to reflect an operation of an accelerator pedal in the amount of the delay.

2. The vehicular active sound effect generating apparatus according to claim **1**, wherein the delay unit gives a delay having a predetermined amount to the sound effect output from the rear speaker when the accelerator opening change exceeds a threshold value.

3. The vehicular active sound effect generating apparatus according to claim **1**, wherein an amplitude of the sound effect output from the rear speaker is set to a value smaller than an amplitude of a sound effect output from the front speaker.

4. The vehicular active sound effect generating apparatus according to claim **1**, wherein the amplitude-adjusted control signal generating unit adjusts the amplitude of the control signal depending on the rotational frequency and the accelerator opening.

5. The vehicular active sound effect generating apparatus according to claim 1, further comprising:

a rotational frequency change calculating unit for calculating a rotational frequency change which represents a change per unit time in the rotational frequency;

wherein the amplitude-adjusted control signal generating unit adjusts the amplitude of the control signal depending on the rotational frequency change and the accelerator opening.

6. The vehicular active sound effect generating apparatus according to claim 1, further comprising:

an entire sound volume corrector for correcting a sound volume of the sound effect depending on a shifted position of a gearshift lever.

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